AC 2012-5275: DEVELOPING AND DESIGNING UNDERGRADUATE LABORATORY WIRELESS SENSOR NETWORK EXERCISES

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David A. Border, Ph.D., holds a principle research interest in electronic information systems. This field includes digital communication and networking and intelligent networked devices. His current work includes wireless sensor networks. Prior research included work on signal bandwidth compression and signal specific data encoding techniques. His technology application interest includes networked systems. Typical teaching duties include junior- and senior-level courses in the Electronics and Computer Technology (ECT) program. Within this course set are the curriculum’s networking and communication courses. As is true with his ECT faculty colleagues, Border supports the program with teaching assignments, as needed, in freshman- and sophomore-level courses offerings. Examples of these include the sophomore level electric circuits and digital electronics courses. Border teaches a digital communication graduate course within the Ph.D. Consortium Technology Management program, as well as other graduate level courses at BGSU.

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I. Introduction

According to Technology Review[1], a magazine of Massachusetts Institute of Technology, the wireless sensor network (WSN) is one of the ten technologies which is going to have a significant effect on many aspects of life. Autonomous, untethered, wireless sensors hold an important place in daily life by making sensor use clear and easy. WSNs have attracted leaders in technology like Intel, Motorola, Atmel, Philips and Siemens[2]. Since its launching at the beginning of the century, WSN have become a new research field worldwide. The number of papers published to improve and develop this technology has been increasing dramatically throughout recent years. By searching the digital libraries of two of the world's leading technical professional associations, the Institute of Electrical and Electronics Engineer (IEEE) and the Association for Computing Machinery (ACM), it has been found that the first paper published about this topic was in the year 2000. More specifically[3] "IEEE shows 3 papers for 2000, 20 in 2001, 34 in 2002, 98 in 2003, 298 in 2004, 622 in 2005, 952 in 2006." European projects have started to fund development of WSNs since 2001. The European Union has decided to finance projects regarding WSNs for its big potential and room for improvement. These projects will last for "at least the next seven years within the Seventh Framework Programme for research and technological development."

As a result of investigation and progress during recent years, WSNs have been under rapid development and became essential in such domains as industrial operations (factory, production, supply chains), health care (home monitoring, biomedical, food safety), environmental (agriculture, habitat preservation), infrastructure (energy, traffic and transportation, flood gauges, bridge stress, power grids, water distribution), and military (battle field awareness, equipments), as well as for research and development.

The aim of this work is to present WSN to students through labs using a commercial wireless sensor Starter Kit from Crossbow Technology (Memsic). These labs will cover WSN hardware, software, programming tools, and applications regarding sensors, and networking. In addition, a WSN Graphical User Interface (GUI) programming application will be introduced.

II. The Apparatus

This section details the general hardware, the sensor and its operating specifications and high level software packages that are native to the Crossbow Starter Kit.

- *General Hardware.*

Crossbow Technology (Memsic) has a widely known and respected reputation in the domain of wireless sensors. It has a strong collaboration with UC Berkeley, which has been developing wireless sensors hardware and software with the Intel Corporation. Crossbow Technology is recognized internationally and is considered a leader in the development of wireless sensors within many products used in scientific and research studies.

For laboratory development, two Crossbow Starter Kits of wireless sensors were used. Each Starter Kit consists of three devices: two wireless sensor nodes (motes) and a base station. The base station allows the link between the computer and the wireless sensors. It is connected to the computer through the Universal Serial Port (USB) while it connects wirelessly, using the Zigbee communications protocol, to the sensor nodes. These nodes are pre-programmed and are able to measure temperature, humidity, barometric pressure, and ambient light, and contain dual-axis accelerometer[4].

The base station is used for wireless data communication with the sensor nodes. It consists of two attached boards, the MIB520 and an IRIS microcontroller board. MIB520 has 2 interfaces, one USB interface and another 51-pin connector. The USB port is used to connect with the computer while the 51-pin connector is used to connect to the IRIS board. In addition, the 51-pin connector is used for direct programming of IRIS boards[8].

The wireless sensor Starter Kit is made for indoor usage and, by default, is programmed to operate in high power mode. The starter kit sensor nodes can use either a high or low XMesh power mode. Both modes provide true mesh network and the ability for every node to route data for other nodes. High power mode uses high bandwidth and sets the radio always "on." On the other hand, the low power mode uses low bandwidth and enables sleeping mode[9].

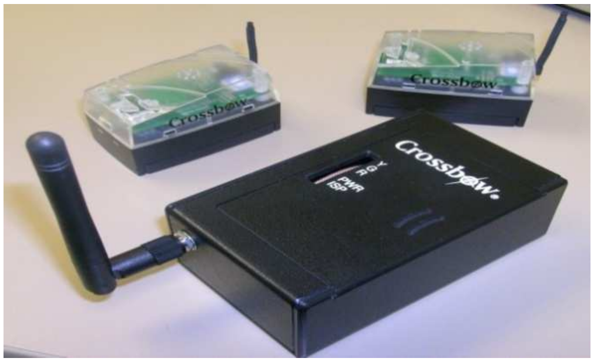


Figure 1. Starter Kit (two wireless nodes and one base station)

- *The Sensor and its Specifications*

The wireless sensor nodes consist of two small module boards attached to each other: the IRIS 2.4GHz module microcontroller board and a multi sensor board MTS400[5]. Both the boards and sensors get their power from 2AA batteries, and the voltage range for them to function properly is between 2.7 and 3.6 V-DC. The MTS400 sensor board can operate a range of temperature; from -10°C to +60°C, as well as a range of humidity; between 0% and 90%[6]. Each sensor has a certain sensor range, accuracy, and power operating range shown in Table 1.

Sensor	**Temperature**	**Humidity**	**Barometric Pressure**	**Light**	**Dual-Axis**
Range	-40°C to 80°C	0-100%	110-300mbar	400-1000nm	±2g
Accuracy	±2°C	±3.5%	±1.5%	-	±17%
Operating Range (Volts)	2.4 to 3.6	2.4 to 3.6	2.2 to 3.6	2.7 to 3.6	3 to 3.6

Table 1. Sensors range, accuracy, and power operating range[7].

- *High Level Crossbow Software Packages*

MoteView[10] (Figure 2) is a monitoring software package from Crossbow for Windows-based machines. This software is used to demonstrate historical and real time charting visualization. It allows setting the data rate for specific or all sensor nodes. It contains several tabs to manage high level functions such as Data, Command, Charts, Histogram, Scatterplot, and Topology, etc. In addition, the front-end package reports server and error messages.

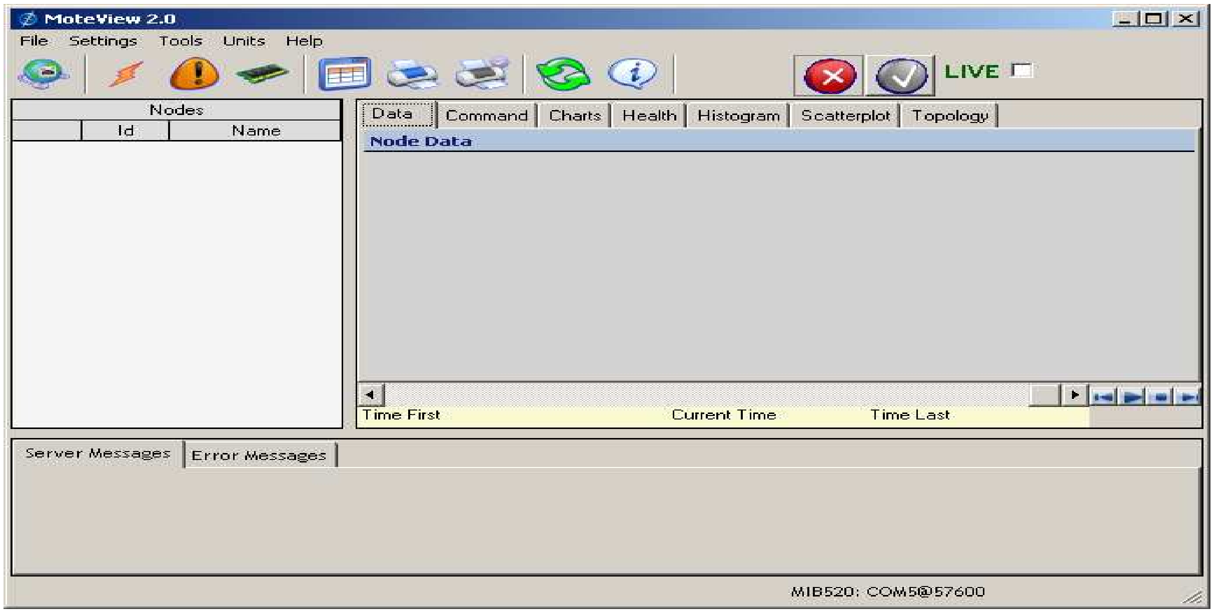
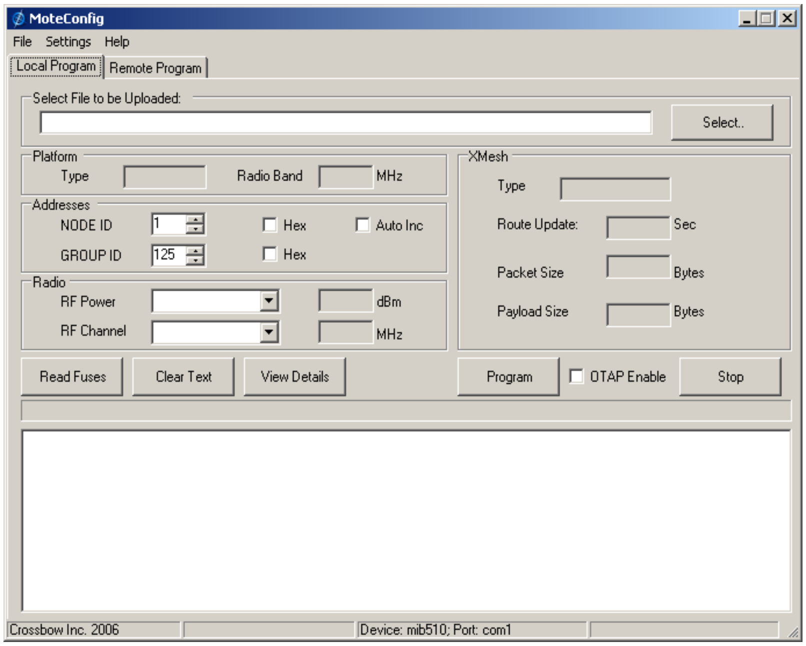


Figure 2. MoteView 2.0 Front Page

MoteConfig (Figure 3) is a programming interface from Crossbow that allows mote programming either in a remote mode (wireless setup) or a local mode (hardwired setup).

MoteConfig enables configuring sensor nodes and permits users to modify the following parameters[11]:

- NODE ID--each node should have unique NODE ID.
- GROUP ID--each network group should have same the GROUP ID.
- RF Power --between zero and 15, starting from 3.2 dBm to -17 dBm. RF power has a direct effect on the range.
- RF Channel--between 11 and 26, starting from 2405MHz to 2480MHz, with an increment of five MHz between each two consecutive channels. RF Channel selection is used to avoid interference with other channels (which might be used in the same area).



NODE ID 1

GROUP ID 125

Crossbow Inc. 2006

Device: mib510; Port: com1

Figure 3. MoteConfig-Local Firmware Programming Dialog Box Tab.

MoteConfig allows some node configuration wirelessly through Over-The-Air-Programming (OTAP) features. Wireless configuration feature makes it possible to program nodes despite the lack of a physical attachment to the base station. OTAP can be used to program nodes between individual high power nodes, or between high power and low power nodes.

III. Commonality between Labs

The five labs developed for undergraduate work share common variables: lab format, tool used, student's knowledge and background, and time available. All labs share the same format since each one includes applications and demonstrations followed by a Student Activity. This format has been found to be suitable since the first part acts as an explanatory lecture for the second part, the Student Activity. Student Activity is significant since it allows students to have their hands on wireless sensor technology. Students will apply, test, and experiment what they have learned and are required to complete all the steps mentioned in the Student Activity and submit their findings as a report.

Another commonality regarding these labs is time availability. The demonstration, experiments, and Student Activity conducted in each lab are constrained to a period of three hours, which is the typical time period for a lab course. The design of these labs should be controlled within one hundred seventy minutes; including equipment setup and troubleshooting. The time range for students to complete the lab will vary according to their competencies. Students with a firm foundation likely will complete each of the labs (observe the demonstration and complete the student activity) in a time period of approximately two hours, while other students might take the whole lab period.

Finally, all labs are written in an appropriate style and form for use by undergraduate students. At this point in time, the laboratories are being integrated into a wireless communication course that features the use of other technologies including WiFi and Bluetooth.

IV. The WSN Work

The intentions behind all the labs are to demonstrate WSN and teach the operating system, programming tools, network and sensing capabilities of wireless sensor devices. The five labs included are Introduction to WSN Starter Kit, Nodes Programming, Network Applications, Sensor Applications, and LabVIEW.

The first lab introduces the hardware and the main software of the kit. The operating system and the programming applications are presented in the second lab. The first two labs provide an operational foundation for students to work with the Lab Three, Four and Five. Lab Three is designed to reveal network capabilities, while Lab Four is intended for sensor applications. Finally, Lab Five brings the WSN Starter Kit equipment and LabVIEW software together.

The software used in the first four labs is MoteView, MoteConfig, Programmers Notepad2, and Cygwin. They are provided in the WSN Starter Kit. As for Lab Five, it uses LabVIEW software from National Instruments.

- *Lab One: Introduction to WSN Starter Kit*

The first lab is essential because students have not had the chance to deal with wireless sensor technology in any prior course. Since students have to connect the WSN nodes and because the electronics technologies programs stress their proficiency with electronic devices, the lab starts with hardware demonstration followed by a demonstration of the graphical user interface software. One-third of the demonstration in Lab One is devoted to covering the kit's hardware while the rest of the demonstration describes the main software. The hardware section starts by covering the two types of nodes, sensor node and base station, followed by a description of their electronic boards: MTS400 board, IRIS board, and the MIB520 board.

Since students are not expected to interface with the sensors with low level software, initially, MoteView, a graphical user interface, has been included in the demonstration. Students are required to gain a proficiency in MoteView as it is used intensely in Lab Three and Four. The demonstration covers MoteView ability to present sensory data in both numerical and visual aspects by going through different tabs like Data, Chart, Histogram, and Topology.

The last part of Lab One demonstration details valuable features of MoteView. They are:

- Setting sampling rate
- Acquiring unique identifier
- Adding an alert
- Exporting the database

One of the common features to sensor's communication is the ability to define operational parameters such as sampling data rate; the WSN kit used is no exception, therefore, setting the sample data rate is covered. As well, users are introduced to device's Unique Identifier (UID). The UID feature allows the system to tag sensor data, uniquely. Setting an alert was included since it is typical in sensory monitoring applications to be alarmed on certain conditions. The end of the demonstration talks about exporting the sensory database. This topic was found necessary to cover since many modern sensory applications have interoperability with other analysis software.

Students are able to complete the steps outlined in the Student Activity following the observation of the lab demonstration section. This activity includes several exercises related to the demonstration part, and the exercises have been designed as follows:

- One exercise to initiate a connection through the PC to the WSN starter Kit
- Three exercises to modify nodes properties and health settings
- Three exercises for configuring visual data representation
- Four exercises for setting sampling rate, acquiring unique identifier, adding an alert, and exporting database

Lab One is imperative since it reveals the main components of the WSN Starter Kit. It has been set as a requirement for all upcoming labs since it informs students about the hardware and software of the kit. As well, this lab allows students to gain a solid understanding for how the Starter Kit works and help them arouse awareness of potential applications.

- *Lab Two: Node Programming*

Taking into consideration that the WSN Starter Kit can be used within different configurations, it has been found necessary to present the applications used for programming. The second lab will also introduce the operating system of the kit, TinyOS and the three different programming environments:

- MoteConfig (Local & Remote).
- Programmers Notepad2.
- Cygwin.

Since the WSN Starter Kit software platform is based on TinyOS which is used by most WSN manufacturers and developers, Lab Two begins its demonstration with a short introduction regarding TinyOS features, including its architecture, components, and native language. Half of the demonstration in Lab Two has been devoted to MoteConfig-Local and Remote programming. The other half of the demonstration, Programmers Notepad2 and Cygwin are covered.

The first application presented for programming the wireless sensor nodes is MoteConfig. The demonstration covers both MoteConfig features for programming, Local and Remote, as well as several network parameters.

Local programming requires physical connection between the base station and the destination programmable board. In contrast to local programming, remote programming is accomplished wirelessly after the nodes have already been placed in a sensory network. Moreover, Local programming can only be implemented to one processor/radio board at a time, while Remote programming can program all the boards across the network at the same time. On the other hand, Local programming allows users to change network parameters, while this feature is inaccessible in Remote programming.

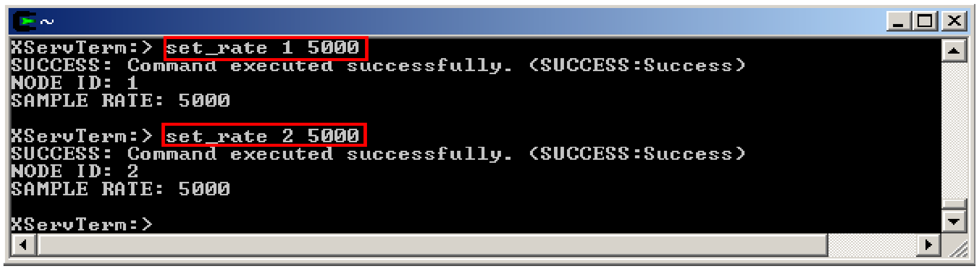
MoteConfig allows setting several network parameters which directly affect the behavior and performance of the sensory network. Such parameters are Node Id, Group ID, RF Power, and RF Channel. Students who have attended some networking courses would be familiar with concepts associated with some of these parameters. These parameters are accessible in Cygwin while they are not accessible in Programmers Notepad2.

Programmers Notepad2 is another integrated development environment used to configure WSN. This environment is similar to compilers whom students have experienced in previous programming classes. Programmers Notepad2 can be used for multiple programming languages, however, in this work its use is limited to the compiling and uploading of nesC code (the program language of TinyOs). It is essential for students completing this lab to be previously acquainted with an understanding of languages like C or Java. Programmers Notepad2 is capable of displaying nesC programming code and students can modify the code before compiling and uploading it to the IRIS board.

Cygwin is an application that provides a Command Language Interface (CLI) similar to Linux. Cygwin acts as the “standard output device” for mote to base station communication. It can also be used as an interface to report sensory values. As well, it allows compiling and uploading codes similar to what have previously been mentioned in Programmers Notepad2. Furthermore, it hosts commands to change nodes settings regarding data rate, node ID, group ID, RF channel, and RF power.

Student Activity in Lab Two has been designed as the following:

- One MoteConfig-based local programming exercise
- One MoteConfig-based remote programming exercise
- One exercise to modify the firmware using Programmers Notepad2.
- One exercise to view sensory data, and execute commands using Cygwin.



```
XServTerm:> set_rate 1 5000
SUCCESS: Command executed successfully. (SUCCESS:Success)
NODE ID: 1
SAMPLE RATE: 5000

XServTerm:> set_rate 2 5000
SUCCESS: Command executed successfully. (SUCCESS:Success)
NODE ID: 2
SAMPLE RATE: 5000

XServTerm:>
```

Figure 4. Cygwin Interface Using XserveTerm to Set Sensor Sample Rate

In summary, this lab has been incorporated to demonstrate the operating system and to introduce three different programming environments. Lab Two develops the student's knowledge and skills learned from previous classes. It facilitates further development for future WSN applications.

- *Lab Three: Network Applications*

The nodes of the Starter Kit are connected in a wireless medium. Therefore, the third lab has been devoted for network applications. This lab has four activities distributed as the following:

- Multiple WSN running simultaneously, using the same frequency without any interference.
- Data routing, single and multi-hop.
- Network connectivity and stability.
- Wireless range.

The design of Lab Three has the same criteria used in earlier labs, one and two. Each activity includes a demonstration regarding a networking feature. Each demonstration offers an illustration to allow a better understanding how the network is connected and the data routes.

To accomplish this lab students will be using two programs, MoteView (presented in Lab One), and MoteConfig, and/or Cygwin (introduced in Lab Two). The Topology tab in MoteView is used to demonstrate how data routes between nodes, while MoteConfig is used to modify group ID, and Cygwin for RF power.

Since multiple WSN kits will be working simultaneously during the labs, Activity One covers avoiding interference between these kits. Each kit will be assigned to a unique Group ID to make sure that each base station is only connected to its designated sensor nodes.
The second activity shows how nodes are self-organizing, and data routing changes automatically from single to multi-hop when nodes position change. Self-healing is covered in the third activity when one of the nodes, the parent node, is eliminated. The elimination forces the WSN to automatically reconfigure its routes, thereby keeping its network operational.

Range is one of the main requirements in building a wireless network, for this reason it has been chosen to dedicate the fourth activity to this property. The wireless kit can be configured with variable values of RF power, which has a direct effect on its connectivity range. Students are able to witness this reduction in broadcast range.

- *Lab Four: Sensor Applications*

The WSN Starter Kit contains variable sensors mounted within each sensory node. Data regarding relative humidity, barometric pressure, ambient light, temperature, and dual-axis accelerometer are all obtainable through the wireless kit. Lab Four includes two activities that allow students interact with the nodes while focusing on two of its sensors. The two activities incorporated in this lab cover the following:

- Validating the presence of light
- Verifying the calibration of temperature.

The design of Lab Four is activity oriented, and the demonstration section does not include new material. Since this lab is focusing on sensors, it has been found beneficial to repeat the specifications regarding light and temperature sensors mentioned in the demonstration of Lab One. MoteView software presented in Lab One is used in both activities. The first activity uses the Topology tab, while the Chart tab is used for the second activity.

The first Student Activity of Lab Four validates the presence of light in three scenarios. The first scenario indicates the presence of light on both nodes, while each of the second and third scenario shows the absence of light on one of the sensor nodes.

The second Student Activity verifies the calibration of temperature. A Fluke multimeter thermocouple is used to obtain independent temperature values. These meter values are compared with the sensor node reported values.

It has been noticed that the temperature obtained by the thermocouple and the two sensor nodes are close but does not match. The slight difference of temperature values is because the node's sensors are placed inside a plastic box, while the thermocouple sensor obtains the temperature values from an end of its wire. Furthermore, sensors sensitivity to noise might vary and could affect the values acquired.

- *Lab Five: LabVIEW*

The fifth lab makes use of a programming a GUI working together with the WSN Starter kit. LabVIEW software is included in electrical engineering technology curricula, and employing it with the kit will add to the student's knowledge regarding how the kit works and creates a foundation for further development. This lab includes two activities:

- Basic Scenario
- Advanced Scenario

Since not all students are routinely familiar with programming the LabVIEW GUI, one-third of the demonstration in Lab Five is dedicated to, introducing/reviewing, LabVIEW software. The demonstration covers two main components of LabVIEW, block diagram and front panel, as well as several VIs related to the WSN Starter Kit.

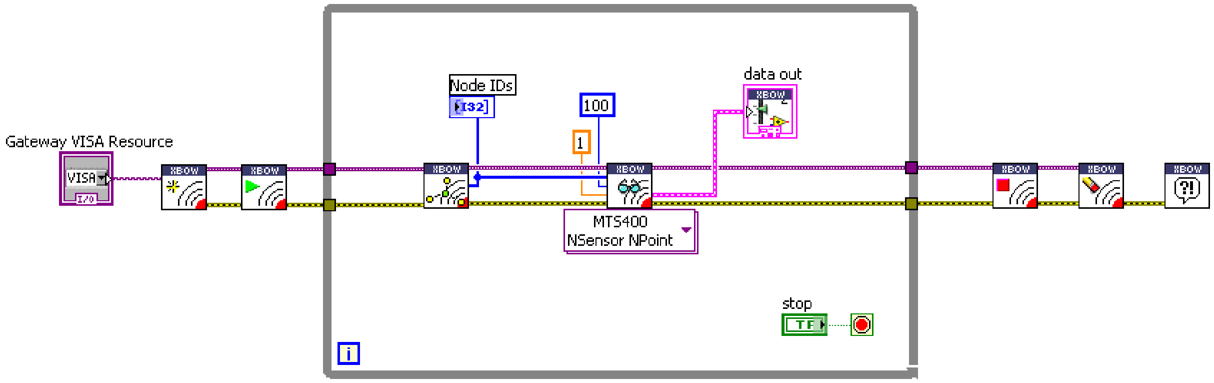


Figure 5. LabVIEW-Block Diagram with Crossbow WSN MTS 400 Sensor

The first activity has been designed to include the basic VIs needed to connect LabVIEW with the kit. These VIs allow LabVIEW software to acquire data from the sensor nodes and display them on the front panel.

The second activity has been made to build over the first one, where additional components have been used in order to allow sensors like temperature and light, to be represented visually. Two thermometers and two charts have been added to allow enhanced sensory data representation.

V. Assessment

Outcomes for student learning within the laboratory work outlined in this paper both general and local. The general outcomes are common to most laboratory coursework, examples of these are:

- the ability to work in teams
- the ability to conduct/complete laboratory work
- the ability to troubleshoot

The local outcomes specific to this senior level WSN laboratory coursework are:

- the ability to work with graphic packages (MoteView, MoteConfig, LabView)
- the ability to work with command line interfaces/tools (Cygwin, Programmers Notepad2)
- the ability to work with the WSN Starter Kit hardware components

The general outcomes, based on the student work observed, are met with the wireless sensor curriculum. To a large degree, the teamwork, working to completion and troubleshooting observed in the course appears within the norms of other senior courses.

The local outcomes, based on the student work observed, vary in direct relationship to student's interests and abilities. It is observed that students who have dual majors in computer science or a minor in computer science do well with the command line interfaces and tools. It is observed that students who do well with working with the WSN Starter Kit hardware components (CPU board and sensor board) are typically students that have performed well in digital electronics lab based coursework. Since the course is new to the curriculum the task of making detailed assessments across multiple laboratory offerings will be performed in the future, as an extension of this work.

VI. Conclusion

WSN is a broad and ever developing technology. This field has attracted leaders in technology and has become essential in many areas. Furthermore, since WSN has huge potential, many leading universities have included it as a component in their curriculum.

This work introduces several aspects related to WSN to technology students. Different labs have been created to allow students to understand and use this technology. These labs have covered multiple areas: an introduction to WSN hardware and software, different environments for nodes programming, network and sensor applications, and client GUI programming using LabVIEW.

The continuing development of WSN will open the door on many recommendations for future work. Based on this work, the following investigations will be considered for future:

- Labs validation to be done by a student test group since this work is designed for academic use and to be applied in a classroom environment.
- Acquiring additional sensor boards like MTS300 since more applications are available through third parties.
- Additional investigation regarding TinyOS operating system and nesC programming language.
- The drivers used with LabVIEW were done by a third party, neither Crossbow Technology Inc, nor National Instruments. A number of the XMesh drivers can be improved to allow better usage of LabVIEW with Crossbow wireless sensor kits.

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